Introduction

Due to complex structures of most of the carbonate reservoir, the needs of reservoir characterization methods is therefore obvious, so that a better description of the storage and flow capacities of a petroleum reservoir can be obtained. Carbonate reservoirs show considerable changes in petrophysical properties within a relatively short intervals due to depositional and diagenetic processes.

Characterization of carbonate reservoirs into flow units have been widely used, where each flow unit would have a reasonably predictable (correlated) property, such as permeability, porosity, water saturation, pore throat radius, flow and storage capacity (Corbett and Potter, 2004). Integration of well-log analyses with core data and geological information would help to improve the reservoir characterization.

The carbonate reservoir under study is a main pay zone a giant oil field, which consists of a main dome with gentle dip. Eight wells were selected so that they are distributed along the field to cover the field laterally and longitudinally.

The structure of this work can be seen as follows. First, the core data were analysed to identify hydraulic units using flow zone indicator (FZI) and the reservoir quality index. Then, pore throat size was estimated using Winland method. Afterwards, log interpretation was implemented, and the data was combined with the core analysis to distribute the flow units vertically.

Core Data Analyses

Fig. 1a shows clear uncorrelated permeability porosity relation. Such behaviour could frequently appear for carbonate reservoirs, where the underlying diagenetic processes and the environmental depositional cause such heterogeneity. However, in order to breakdown this complexity, the reservoir was classified into hydraulic units using flow zone indicator and reservoir quality index, as follows:

\[
\log FZI = \log RQI - \log \varphi_z
\]  

and reservoir quality index is then:

\[
RQI = 0.0314z \sqrt{\frac{k}{\phi_e}}
\]

\[
\varphi_z = \frac{(\varphi_e / (1 - \varphi_e))}{1 - \varphi_e}
\]

Where RQI is the Reservoir Quality Index (um), \( \varphi_z \) is the Normalized Porosity Index and \( \varphi_e \) is the effective porosity. A log-log plot of data from a given flow unit or similar FZI value will be situated on a straight line with a slope of 1.0. The other flow units will fall on adjacent parallel lines. Each flow unit will have a separate FZI value. Fig. 1b exhibits six hydraulic units, where the hydraulic units Group (0) has the worst petrophysical properties among the others, while Group 5-9 was the better. However, within each hydraulic unit there is a considerable difference in the petrophysical properties, where this variation brings the need to subdivide each hydraulic unit based on the pore throat size, so that we used Winland method. The Winland equation can be given as follows (Kolodzie, 1980):

\[
\log r35 = 0.732 + 0.588 \log ka - 0.864 \log \varphi
\]

where, 
R35: the pore throat radius (microns) corresponding to the 35th percentile, \( ka \): the uncorrected air permeability (md), and \( \varphi \): porosity (%). r35 also can be utilized to classify the reservoir into rock type, e.g. rocks have \( r35 > 10 \mu m \) will be classified as mega pore throat, while those have \( r35 < 0.5 \mu m \) will be considered as micro pore throat. Fig. 1b shows that hydraulic unit Group (0) has mainly micro pore throat and some meso pore throat, while Group (3) has four different pore throat types. This additional information would help to assign the best interval in terms of pore throat within the hydraulic units, e.g. intervals have micro pore throat would not be recommended to be perforated.
**Figure 1** Permeability versus porosity obtained from core data for the carbonate reservoir under study, where (a) shows heterogeneous raw data, while (b) displays the data after classifying the hydraulic units, pore throat size ($r_{35}$) and pore type.

**Well-log Interpretation**

The vertical variation in water saturation, residual oil saturation, porosity and lithology should be identified in order to have the necessary knowledge to divide the reservoir vertically into flow units and obtain accurate description of those flow units. So, full well log interpretations were carried out. Dual Induction log (ILd), dual Laterolog (LLd) and Micro Spherically Focused Log were analysed to calculate the true resistivity ($R_t$) and the resistivity of the invaded zone ($R_{xo}$). Interactive Petrophysics software (IP) was utilized to implement the well-logs environmental corrections by using Schlumberger correlations. The neutron–density cross plot was then initiated to estimate the lithology of each recorded interval, see Fig. 2.

**Figure 2** Neutron porosity (x-axis) versus density (y-axis) of two selected wells.

After, arithmetic average of neutron porosity and porosity obtained from density log was considered to calculate the total porosity, as suggested by Schlumberger, (2016). The formation Water Resistivity ($R_W$) was obtained from the salinity reports and calibrated against the $R_W$ which estimated using by Sp-Log. Determination of Archie parameters using Pickett's Method (1966) was considered, where the following logic describes the basis of this method:

$$R_t = \frac{a R_w}{\phi^m S_w^n}$$  \((5)\)

Where, $S_w$: the water saturation (fraction), $R_w$: the water resistivity (ohm-m), $R_t$: formation resistivity (ohm-m) and $a$, $n$, and $m$: Archie’s parameters (dimensionless). Taking the logarithms of both sides’ equation (5) becomes:

$$\log R_t = -m \log \phi + \log a R_w - n \log S_w$$  \((6)\)
In a water-bearing zone $S_w = 1$:

$$\log R_t = - m \log \phi + \log a R_w$$

(7)

Equation (7) is a straight line on log-log plot, where $m$ is the slope and $(a.R_w)$ is the intercept at $\phi=1$. As $R_w$ is known from other sources (SP usually), $(a)$ can easily be found. To be concise, more details and the results of this method are not shown here. Then, water saturation was calculated using Archie Equation as in Eq. 5. **Fig. 3** shows the resulted well-log interpretations for two example wells, using IP-software. Similar interpretation was also conducted for the other wells.

**Figure 3** Well log interpretation of two wells under study.

**Flow units Analyses**

The analyses were then gathered using Petrel software. Additional analyses that is not mentioned here is that the modified Lorenz cross plot was used to identify the flow and storage capacities. After correlating the core data analyses with the well log interpretation, the reservoir was divided into fifteen flow units, while it was previously divided into only three geological layers based on the nature of the rock. **Fig. 4** shows a cross sectional plot of laterally continuous flow units that appears in four different wells that cross the main dome in the reservoir.
Conclusion

In order to obtain better characterization of the petrophysical properties, the carbonate reservoir was divided into fifteen flow units in the aid of core data analyses and well log interpretations. This updated characterization of the reservoir would help to better estimate the fluid flow behaviour for reservoir modelling reasons.

References
